

PATENT APPLICATION
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of

for

ANTIREFLECTIVE COATING LAYER

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1 between components. Attempts to isolate components from each other in the prior art are
2 constrained by photolithographic limits of about 0.25 microns. One way to form structures
3 that electrically isolate conductive materials on a semiconductor substrate from each other
4 is to use photolithography in patterning dielectrics layers upon the semiconductor substrate.

5 To form a metallization wiring layer on a semiconductor substrate by
6 photolithography, a photoresist mask is used to pattern the metallization wiring layer. The
7 mask has directed therethrough a beam of light, such as ultraviolet (UV) light and deep UV
8 (DUV) light (~250 nm), to transfer a pattern through an imaging lens from a
9 photolithographic template to a photoresist coating which has been applied to the structural
10 layer being patterned. The pattern of the photolithographic template includes opaque and
11 transparent regions with selected shapes that match, respectively, openings and intact
12 portions intended to be formed into the photoresist coating. The photolithographic template
13 is conventionally designed by computer assisted drafting and is of a much larger size than
14 the semiconductor substrate on which the photoresist coating is located. Light is directed
15 through the photolithographic template and is focused on the photoresist coating in a manner
16 that reduces the pattern of the photolithographic template to the size of the photolithographic
17 coating and that develops the portions of the photoresist coating that are unmasked and are
18 intended to remain. The undeveloped portions are thereafter removed. Other
19 photolithographic techniques for formation of device features are also possible.

20 As dimensions shrink below about 0.25 microns, the prior art technique of forming
21 metallization wiring layers becomes more difficult to achieve. Light that is reflected during
22 exposure of a photoresist tends to blur the boundary between two metallization lines and the
23 space therebetween. This blurring can cause wider metallization lines than designed, which
24 excessive width will either bridge and short out the circuit or will cause unwanted "cross
25 talk" such that the device is rendered defective.

The resolution with which a pattern can be transferred to the photoresist coating from the photolithographic template is currently limited in commercial applications to widths of about 0.25 microns. In turn, the dimensions of the openings and intact regions of the photoresist mask, and consequently the dimensions of the shaped structures that are formed with the use of the photoresist mask, are correspondingly limited. Photolithographic resolution limits are thus a barrier to further miniaturization of integrated circuits. Accordingly, a need exists for an improved method of forming semiconductor device features that have a size that is reduced from what can be formed with conventional photolithography.

During photolithography, reflected light that occurs during exposure of a mask tends to blur the desired image because the reflected light escapes beyond exposed regions on the photoresist. The blurring problem is caused by reflected light affecting areas of the photoresist that are outside the design pattern.

Figure 1 illustrates the problem of blurring caused by reflected light that occurs during exposure of a photoresist. A semiconductor structure 10 may be, for example, a semiconductor substrate 12 that was designed to have a width D, but due to blurring caused

by reflectivity of patterning light from structures beneath the photoresist, semiconductor substrate 12 has an actual width A. The variance between design width D and actual width A is illustrated as the distance $2(B/2)$ or B. By way of example, semiconductor substrate 12 was designed to have a width D of 10 in arbitrary units, but due to blurring caused from reflectivity, the actual width A is nine in arbitrary units. It can be seen that a ten percent variance between design and actual width has occurred.

As miniaturization technology continues, a blurring variance of B as illustrated in Figure 1 will increase relative to an ever-decreasing design width D. Thus, as also illustrated in Figure 1, a miniaturized semiconductor substrate 12' that may have a design width D' of two and one-half in arbitrary units but with the variance of B, will have the effect of causing a 40 percent error. A variance of B may leave insufficient space upon miniaturized semiconductor substrate 12' to form desired contacts or structures. It can be seen from the demonstration illustrated in Figure 1 that the need to eliminate or substantially reduce blurring must keep pace with miniaturization.

Another hindrance to photolithographic limitations are conventional antireflective coating (ARC) schemes. Prior art methods for avoiding reflected light and its photoresist blurring problems include using layers such as titanium nitride or organic materials that reduce the reflected light in order to better control resolution of the photoresist. As the ever-increasing pressure to miniaturize bears upon the microelectronics industry, the conventional antireflective enhancements such as a titanium nitride layer, organic layers, or other layers known in the art are proving inadequate at resolutions below about 0.25 microns.

One problem at a dimension below about 0.25 microns is that of fouling caused by titanium nitride or organic materials. Fouling is defined as a tendency for a selected antireflective layer to resist staying within preferred boundaries. Resistance to staying within preferred boundaries tends to cause photolithographic techniques to be compromised.

1 When the ARC is a polymer film, it is applied directly to the semiconductor
2 structure to a thickness of about 0.5 microns and photoresist is deposited on top of the ARC.
3 The ARC then has the function of absorbing most of the radiation used during exposure of
4 the photoresist that penetrates the photoresist material. Both standing wave effects and
5 destructive scattering of light due to topographical features are suppressed with use of the
6 ARC. A disadvantage of a polymer film ARC is that the process is increased in complexity
7 and dimensional control may be lost. A polymer film ARC requires application by spin
8 coating of the ARC material and pre-baking of same before applying the photoresist material.
9 A problem of removing the ARC exists following an etch. For example, during anisotropic
10 etching, portions of a photoresist are mobilized and form a liner within a recess that is being
11 etched that further assists in achieving the anisotropic etch. Due to the anisotropic etch,
12 however, the photoresist that was mobilized may have mingled with other elements that
13 cause it to resist removal by conventional stripping techniques. This resistance to stripping
14 requires stripping solutions that have a chemical intensity that may detrimentally effect the
15 structure that was achieved during the anisotropic etch. As such, use of a substance that is
16 intended to aid anti-reflectivity can result in the benefit thereof being mitigated by the
17 requirement of a more chemically intensive stripping solution treatment.

18 Various attempts have been made to form antireflective coatings in order to further
19 enhance miniaturization. One type of antireflective coating that has been developed includes
20 metal nitrides, such as titanium nitride, and metal silicon nitrides. The prior art use of metal
21 silicon nitrides and metal nitrides was developed for resolution limits at or above about 1.0
22 microns. At that resolution limit, there was little or no concern about the phenomenon called
23 "foot poisoning" of the photoresist. Foot poisoning is the phenomenon of diffusion of a
24 constituent of the antireflective layer out of the antireflective layer and into the photoresist
25 material. Foot poisoning has the problem of changing the physical qualities of the
26 photoresist material during processing so as to cause the photoresist material immediately

1 adjacent to the antireflective layer to spread or otherwise change. Figures 2-4 illustrate the
2 phenomenon of foot poisoning as it develops during photoresist processing. In Figure 2 it
3 can be seen that semiconductor structure 10 includes semiconductor substrate 12. Upon
4 semiconductor substrate 12 there may be an insulation layer 14 such as borophosphosilicate
5 glass (BPSG), or a silicate formed from tetraethylorthosilicate (TEOS) decomposition, or the
6 like. Upon insulation layer 14 there is disposed a metallization layer 16 that is to be
7 patterned into a system of superficial metallization lines. A prior art metal silicide or metal
8 silicon nitride antireflective layer 18 is disposed upon metallization layer 16 and a masking
9 layer 20 is disposed upon antireflective layer 18.

10 During processing of masking layer, as seen in Figure 3, a critical dimension D_C is
11 formed by exposing masking layer 20 to form a patterned mask 22. During curing of
12 patterned mask 22, nitrogen diffuses from antireflective layer 18 into patterned mask 22 and
13 causes patterned mask 22 to expand at the interface between patterned mask 22 and
14 antireflective layer 18. As seen in Figure 4, patterned mask 22 has formed a foot-poisoned
15 mask 24 in which the critical dimension D_C has been lost and an actual dimension, D_A has
16 resulted. When critical dimensions are in the range of about 0.5 to 1 microns, foot poisoning
17 may not be a major concern. However, the trend of miniaturization has progressed to the
18 point at which a resulting D_A in lieu of D_C is an undesirable variance. The need to reduce or
19 eliminate foot poisoning can be appreciated as analogous to the need to reduce or eliminate
20 blurring as illustrated in Figure 1. In other words, foot poisoning effects must be reduced in
21 a manner that keeps pace with the process of miniaturization.

22 Another method of attempting to avoid reflected light is to use a metallic mask.
23 Metallic materials, however, can cause contamination of the semiconductor structure beneath
24 due to the high mobility of metal ions in wet chemical environments or in dry-etch vapors.
25 Additionally, although a metallic mask may remain as part of a finished semiconductor
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What is needed is an antireflective coating scheme that does not substantially add to fabrication cost and does not substantially reduce fabrication yield. What is also needed is an antireflective coating scheme that imparts an antireflective quality to photolithographic techniques not previously achieved in the prior art. What is also needed is an antireflective coating scheme that does not cause fouling of the semiconductor structure. Additionally, what is needed is an antireflective coating scheme that either does not require removal, or that can be removed without causing contamination or damage to the semiconductor structure. What is also needed is an antireflective coating scheme that facilitates a better photoresist profile and better control of critical dimensions due to better prevention of reflected light than is found in the prior art. What is also needed is an antireflective coating scheme that, while resisting reflecting light, resists foot poisoning of the photoresist during processing.

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1 Minimum reflectivity may be manipulated by adjusting the thickness of the
2 antireflective layer. Minimum reflectivity may also be manipulated by nitrogen content in
3 the inventive antireflective layer.

4 Tungsten is a preferred transition metal in the fabrication of the inventive
5 antireflective coating. A preferred tungsten silicide target for the PVD process will have a
6 composition of silicon between 1 and 4 in stoichiometric ratio to tungsten.

7 The inventive antireflective layer is amorphous or has a preferable grain size that is
8 less than the film thickness of the antireflective layer. A grain size that is substantially the
9 same or larger than the film thickness of the inventive antireflective layer will cause a
10 substantially discontinuous film to form. A substantially discontinuous film will
11 detrimentally allow for reflected light to escape from the metallization layer that is to be
12 patterned.

13 Composite antireflective layers made of metal silicides or metal silicon nitrides may
14 be fashioned according to the present invention depending upon a specific application.

15 Another type of composite antireflective layer may be made according to present
16 invention in which antireflective layers made of metal silicides or metal silicon nitrides may
17 be combined with rough or hemispherical grained polysilicon. In this embodiment, it may
18 be advantageous to use the polysilicon as a later-used conductive layer such as the
19 conductive material in a word line or as an etch stop structure.

20 The reflectivity exhibited by antireflective structures of the present invention can be
21 described as the fraction of incident light energy that escapes from the surface of the
22 antireflective structure when irradiated by photoresist patterning light under normal operating
23 conditions.

24 In connection with preferred materials and preferred reflectivities of selected
25 structures, it is also useful to describe the present invention in terms of a variance from the
26 design geometry of an actual characteristic geometry of the structure being fabricated. It can

The method of the present invention may be used to form various structures such as metallization layers. It is to be understood that the discussion of metallization layers is merely illustrative and not limiting of the inventive method. For example, isolation trenches, contact corridors, vias, stacked storage node wells, and wiring trenches are further non-limiting examples of structures that may also be formed by the inventive method and by use of the inventive antireflective structure.

BRIEF DESCRIPTION OF THE DRAWINGS

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2 In order that the manner in which the above-recited and other advantages of the
3 invention are obtained, a more particular description of the invention briefly described above
4 will be rendered by reference to specific embodiments thereof which are illustrated in the
5 appended drawings. Understanding that these drawings depict only typical embodiments of
6 the invention and are not therefore to be considered to be limiting of its scope, the invention
7 will be described and explained with additional specificity and detail through the use of the
8 accompanying drawings in which:

9 Figure 1 is an elevational cross-section view of a semiconductor structure,
10 illustrating the variance between a design dimension and an achieved dimension caused by
11 the blurring effect of reflected light in the distortion of sub-micron critical dimensions in
12 conventional photolithography.

13 Figure 2 is an elevation cross-section view of a semiconductor structure wherein an
14 insulation layer is disposed upon a semiconductor substrate, a layer of metallization is
15 disposed upon the insulation layer, an antireflective layer is disposed upon the layer of
16 metallization, and a masking layer is disposed upon the antireflective layer.

17 Figure 3 is an elevation cross-section view of the semiconductor structure depicted
18 in Figure 2, wherein the masking layer has been patterned to form a patterned mask with an
19 ideal patterned critical dimension.

20 Figure 4 is an elevation cross-section view of the semiconductor structure in
21 Figure 2, wherein the masking layer has been patterned to form a patterned mask, and
22 wherein the phenomenon of foot poisoning is illustrated such that a critical dimension has
23 been altered.

24 Figure 5 is a graph of the fraction of total reflectivity as a function of wavelength for
25 a metal silicon nitride antireflective layer of a given chemical makeup for a series of varying
26 thicknesses.

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Figure 6 is a graph of the fraction of total reflectivity as a function of wavelength that illustrates the effect of measured reflectivity for antireflective layers that differ in nitrogen processing conditions during formation of the antireflective layer.

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centimeters per minute (sccm). Thus, 30/20 represents 30 sccm Ar and 20 sccm N₂.

As it has been found that the presence of Si aids in resisting N₂ diffusion from the antireflective layer into the photoresist, a relationship is maintained that generally relates an increase of N₂ in the sputtering gas to an increase in Si in the net sputtering target. Thus, under similar sputtering conditions, the amount of N produced in an antireflective layer according to the present invention in a WSi₂ or a WSi_{2.55} target will preferably be less than the amount of N produced in an antireflective layer in a WSi_{2.7} target.

Figure 5 is an illustration of measured reflectivity of total incident light as a function of light wavelength. In Figure 5, five antireflective layers are depicted according to their specific measured reflectivities. The five antireflective layers have similar chemical compositions but have varying thicknesses. The curves in Figure 5 are labeled with reference numerals 85 through 200. Each reference numeral corresponds to a thickness of the inventive antireflective layer in Angstrom units (Å). The inventive antireflective layer was made by sputtering a titanium silicide target comprising a $\text{TiSi}_{2.55}$ composition. Sputtering was carried out under the conditions of one kilowatt sputtering power, 400-700 volts sputtering potential, and a 30/20 Ar/N_2 sccm flow rate and ratio. The 200 Å thick antireflective layer was sputtered at 1 kW for ten seconds; the 160 Å thick antireflective layer was sputtered at 1 kW for eight seconds; the 120 Å thick antireflective layer was sputtered at 1 kW for six seconds; the 100 Å thick antireflective layer was sputtered at 1 kW for five seconds; and the 85 Å thick antireflective layer was sputtered at 0.8 kW and five seconds.

A simple linear regression of the observed approximate minimum reflectivities of the antireflective layers illustrated in Figure 5 demonstrates a substantially linear relationship between thickness of the inventive antireflective layer and minimum reflectivity. The 85 Å film has the minimum reflectivity right at the DUV wavelength (~250 nm).

Minimum reflectivity may also be manipulated by nitrogen content in the inventive antireflective layer. Figure 6 illustrates measured reflectivity of two inventive antireflective

1 layers, each having a thickness of about 120 Å, but having differing concentrations of
2 nitrogen therein. Each antireflective layer was fabricated under the conditions of 1 kW
3 sputtering power, six seconds sputtering time, and a $\text{WSi}_{2.55}$ tungsten silicide sputtering
4 target. The sputtering conditions variable was the nitrogen content in the sputtering gas as
5 illustrated by curves 30/30 and 30/20. It can be seen that sputtering with a higher nitrogen
6 ratio in the sputtering gas for a 120 Å thick antireflective layer fabricated will have a lower
7 minimum reflectivity than sputtering with a 30/20 Ar/ N_2 ratio. It also has a lower
8 wavelength towards DUV at this minimum reflectivity.

9 Tungsten is a preferred transition metal in the fabrication of the inventive
10 antireflective coating. Tungsten is preferred because of its ability to form fine (*i.e.* less than
11 5 nm) grains of tungsten silicon nitride. Tungsten is also preferred because at a grain size
12 of 5 nm or smaller, tungsten grains are substantially amorphous.

13 A preferred tungsten silicide target will have a composition of silicon between 1 and
14 4 in stoichiometric ratio to tungsten. A more preferred tungsten silicide target will have a
15 composition of silicon between 2 and 4 in stoichiometric ratio to tungsten. Another preferred
16 target will have a silicon to tungsten ratio between 3 and 4. Commercially available tungsten
17 silicide targets may be used and sputtered at different voltage potentials in order to achieve
18 a preferred sputtering ratio of tungsten to silicon. For example, a low energy sputtering, *e.g.*
19 a sputtering at a potential between 400 and 700 volts at 1 kW, will tend to have a less
20 preferential sputtering between the tungsten and silicon components in the target. At higher
21 energy sputterings, preferential sputtering for tungsten over silicon may occur.

22 The inventive antireflective layer has a preferable grain size that is less than the film
23 thickness of the antireflective layer. A grain size that is substantially the same or larger than
24 the film thickness of the inventive antireflective layer will cause a substantially discontinuous
25 film to form. A substantially discontinuous film will allow for reflected light to escape
26 from, for example, the metallization layer 16 that is to be patterned.

1 It can now be appreciated that a grain size that is substantially 5 nm or less and/or
2 substantially amorphous such as including tungsten, fabricated under the conditions set forth
3 in the specification, can be found using other refractory or transition metals by reading the
4 specification and by routine experimentation.

5 Structures

6 Composite antireflective layers made of metal silicides or metal silicon nitrides may
7 be fashioned according to the present invention depending upon a specific application. In
8 many applications, it is presupposed that a metallization layer such as metallization layer 16
9 is being overlayed with the inventive antireflective layer.

10 Another type of composite antireflective layer may be made according to present
11 invention in which antireflective layers made of metal silicides or metal silicon nitrides may
12 be combined with rough or hemispherical grained polysilicon. In this embodiment, it may
13 be advantageous to use polysilicon as a later-used conductive layer such as the conductive
14 material in a word line or as an etch stop structure.

15 Reflectivity

16 The reflectivity exhibited by antireflective structures of the present invention can be
17 described as the fraction of incident light energy that escapes from the surface of the
18 antireflective structure when irradiated by photoresist patterning light under normal operating
19 conditions. Various ways of describing reflectivity may be expressed. For example, a simple
20 fraction of incident light energy may be given for a preferred reflectivity as illustrated in
21 Figures 5 and 6. A preferred reflectivity for the present invention is in a range from about
22 0 to about 30 percent, more preferably from about 5 to about 20 percent, and most preferably
23 from about 10 to about 15 percent.

24 Figure 5 illustrates the reflectivity of metal silicon nitride antireflective layers as a
25 function of incident light wavelength. Standard conditions for the antireflective layers
26 include fabrication thereof from a $\text{WSi}_{2.55}$ target with a sputtering gas flow ratio of Ar/N of

30/20. In each case, sputtering was carried out under 1 kW power conditions, and sputtering times were varied in order to achieve a selected range of thicknesses. It can be seen from the reflectivity curves in Figure 5 that minimal reflectivity for antireflective layers made of metal silicon nitride material is a function of layer thickness for the layer thickness tested. Linear regression of approximate minimal reflectivity as a function of layer thickness reveals a substantially linear relationship therebetween. It can also be seen that the minimal reflectivity of the inventive metal silicon nitride antireflective layers is in the DUV wavelength range of below about 400 nm.

A second set of antireflective layers was made to discover the effect of nitrogen content therein upon reflectivity. Figure 6 illustrates two antireflective layers of metal silicon nitrides that were made from a $\text{WSi}_{2.55}$ target with sputtering gas flow ratios of Ar/N of 30/20 and 30/30. As it can be observed, the antireflective layer that was sputtered from a $\text{WSi}_{2.55}$ target with a sputtering gas flow ratio of Ar/N of 30/20 has a lower overall reflectivity than the antireflective layer that was sputtered from a $\text{WSi}_{2.55}$ target with a sputtering gas flow ratio of Ar/N 30/30. The same trend can also be used with increasing silicon content in a tungsten silicide target.

By understanding the relationships illustrated in Figures 5 and 6, materials may be selected by using such relationships as, for example, the Beer-Lambert law:

$$I = I_0 \exp(-\epsilon \rho d) \quad (1),$$

where I is the reflected light intensity, I_0 is the initial light intensity, ϵ is the black-body degree of opacity or light extinction coefficient of the material, ρ is the density of the material, and d is the measured distance from the surface of the antireflective structure to a detector.

It can be appreciated that various metal silicon nitride combinations can be selected and tested that can be compared with the antireflective layers taught herein. It can be further appreciated that one of ordinary skill in the art will be able to select from fouling-resistant,

light-dissipating, and light-absorbing combinations, and that a relationship between ρ and ϵ can be used to choose equivalent materials to those that are disclosed herein.

Blurring Effects

In connection with preferred materials and preferred reflectivities of selected structures, it is also useful to describe the present invention in terms of a variance from the design geometry of an actual characteristic geometry of the structure being fabricated. A mask may be designed with a first preferred characteristic geometry and, as illustrated in Figure 1, the actual geometry exposed in photolithography will vary from the design geometry. With geometries contemplated by the present invention, a variance of less than 10 percent is preferred and a variation of less than 5 percent is most preferred. It can be appreciated that, as integrated circuit device geometries continue to shrink, the variance preferably either remains relatively constant or must also shrink.

Applications

The method of the present invention may be used to form various structures with preferred geometries such as metallization layers. It is to be understood that the discussion of metallization layers is merely illustrative and not limiting of the inventive method. For example, isolation trenches, contact corridors, vias, stacked storage node wells, and wiring trenches are further non-limiting examples of structures that may also be formed by the inventive method and by use of the inventive antireflective structure.

Preferred geometries of the present invention are geometries below 0.25 microns. More preferred geometries achieved by using the inventive antireflective layer are geometries below about 0.22 microns. Even more preferred geometries are below 0.2 microns. Highly preferred geometries are achieved below 0.1 microns, and the present invention may be used to achieve patterning geometries of about 0.07 microns.

82) The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered

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What is claimed and desired to be secured by United States Letters Patent is: